16.842
Fundamentals of Systems Engineering

Integrated Lifecycle Management and Modeling

4 December 2009

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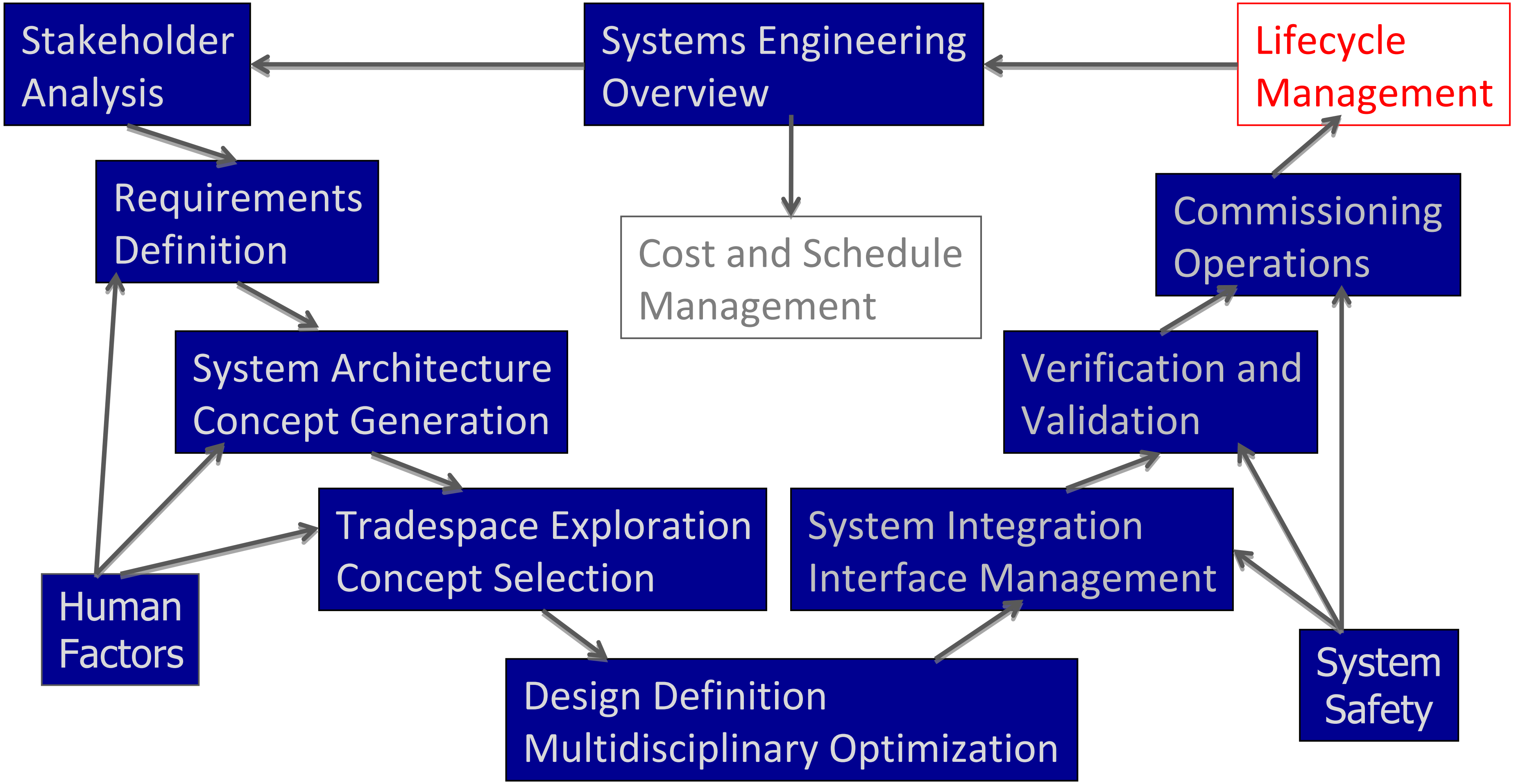
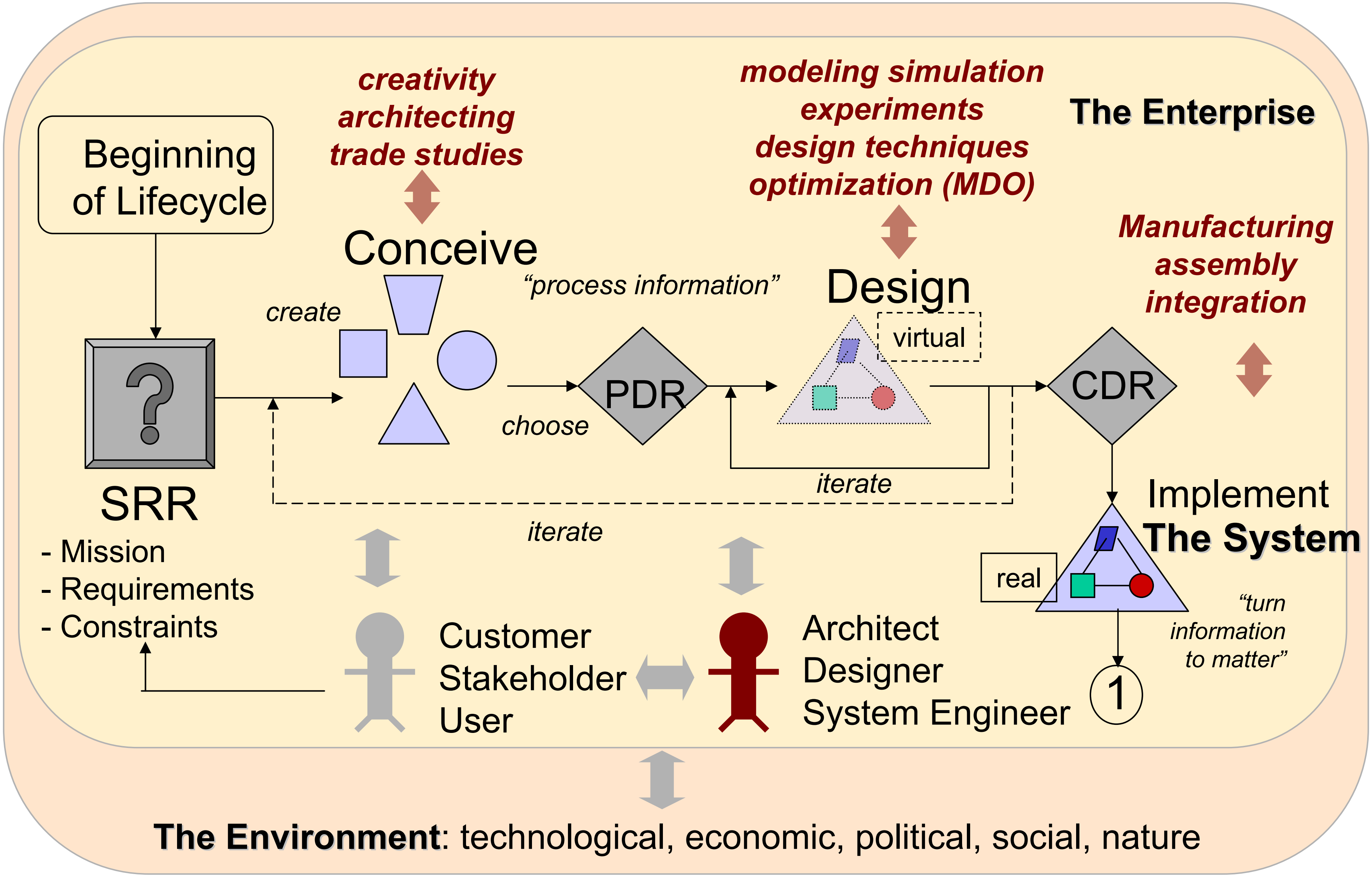
V-Model – Dec 4, 2009



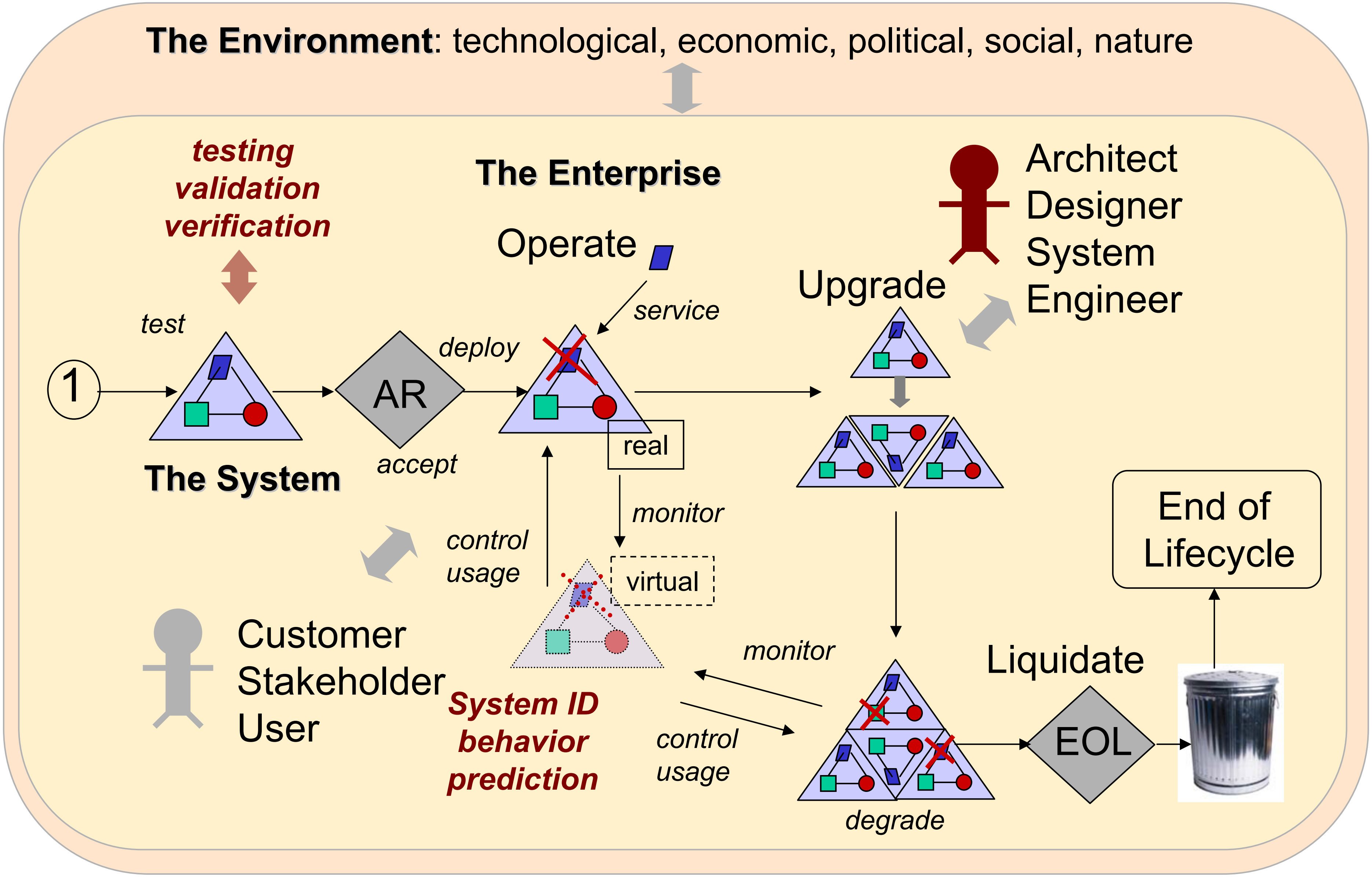
Today's Topics

- Lifecycle Management
  - First part: Conceive and Design
  - Second part: Implement and Operate
- Lifecycle Modeling and Process
  - What to model across lifecycle?
  - Value Modeling and Optimization framework
- Summary and last Announcements

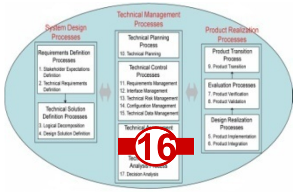
Lifecycle Management

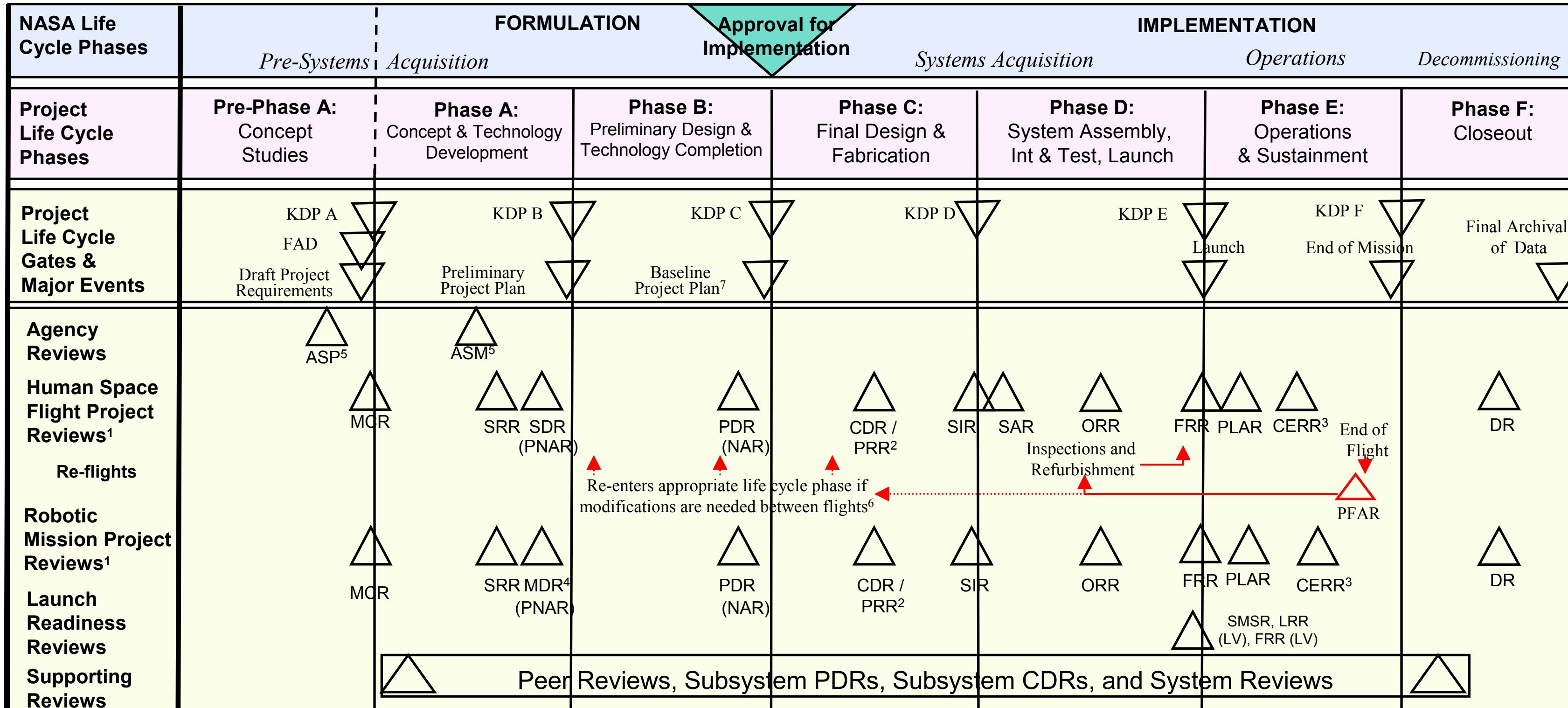


Lifecycle Management (cont.)



NASA Life-Cycle Phases





FOOTNOTES

1. Flexibility is allowed in the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.

ACRONYMS

ASP—Acquisition Strategy Planning Meeting
ASM—Acquisition Strategy Meeting
CDR—Critical Design Review
CERR—Critical Events Readiness Review
DR—Decommissioning Review
FAD—Formulation Authorization Document
FRR—Flight Readiness Review
KDP—Key Decision Point
LRR—Launch Readiness Review
MCR—Mission Concept Review
MDR—Mission Definition Review
NAR—Non-Advocate Review
ORR—Operational Readiness Review
PDR—Preliminary Design Review
PFAR—Post-Flight Assessment Review
PLAR—Post-Launch Assessment Review
PNAR—Preliminary Non-Advocate Review
PRR—Production Readiness Review
SAR—System Acceptance Review
SDR—System Definition Review
SIR—System Integration Review
SMSR—Safety and Mission Success Review
SRR—System Requirements Review

Lifecycle Modeling

MIT esd ISO/IE 15288 Lifecycle Processes

Enterprise Processes
- Enterprise Environment Management Process
- Investment Management Process
- System Life Cycle Management Process
- Resource Management Process
- Quality Management Process

Agreement Processes
- Acquisition Process
- Supply Process

Project Processes
- Project Planning Process
- Project Assessment Process
- Project Control Process
- Decision-making Process
- Risk Management Process
- Configuration Management Process
- Information Management Process

Technical Processes
- Stakeholder Requirements Definition Process
- Requirements Analysis Process
- Architectural Design Process
- Implementation Process
- Integration Process
- Verification Process
- Transition Process
- Validation Process
- Operation Process
- Maintenance Process
- Disposal Process

- What should we model?

Optimal Lifecycle Design

- Traditionally, design has focused on **performance**

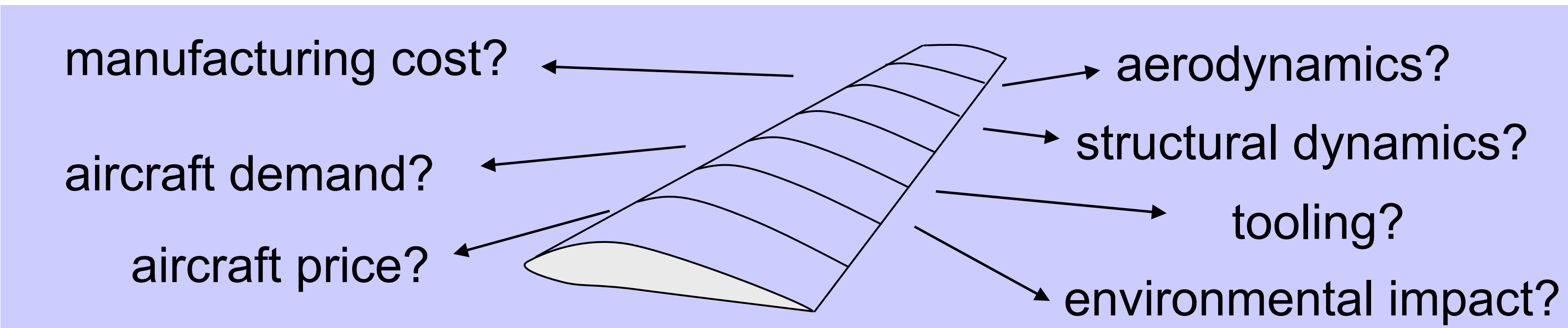
  e.g. for aircraft design

  optimal = minimum weight

- Increasingly, **cost** becomes important
- 85% of total lifecycle cost is locked in by the end of preliminary design.
- But *minimum weight* $\neq$ *minimum cost* $\neq$ *maximum value*
- What is an appropriate value metric?

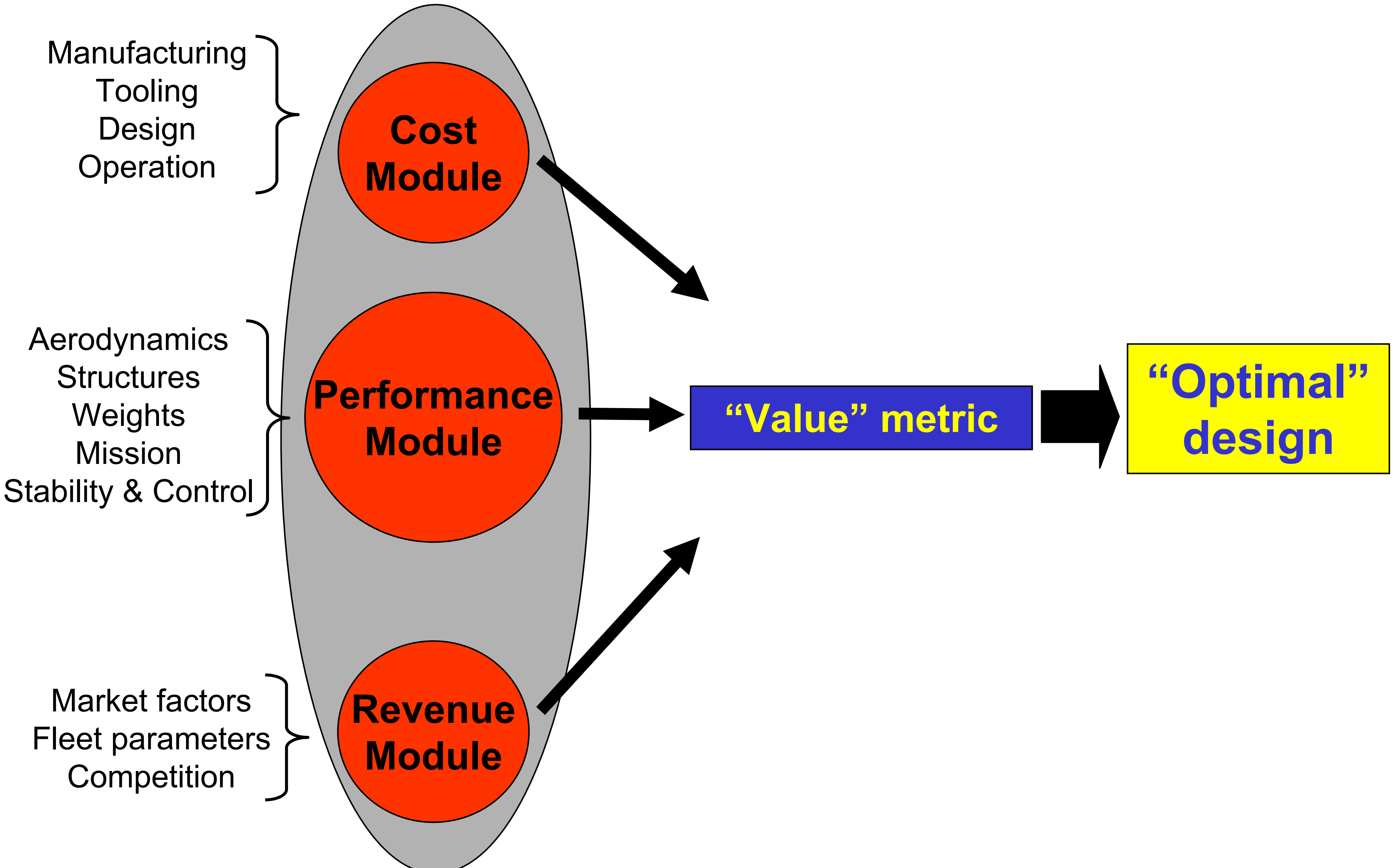
Design Example

- We need to design a particular portion of the wing
- Traditional approach: balance the aero & structural requirements, minimize weight
- We should consider cost: what about an option that is very cheap to manufacture but performance is worse?



- How do we trade performance and cost?
- How much performance are we willing to give up for $100 saved?
- What is the impact of the low-cost design on price and demand of this aircraft?
- What is the impact of this design decision on the other aircraft I build?
- What about market uncertainty?

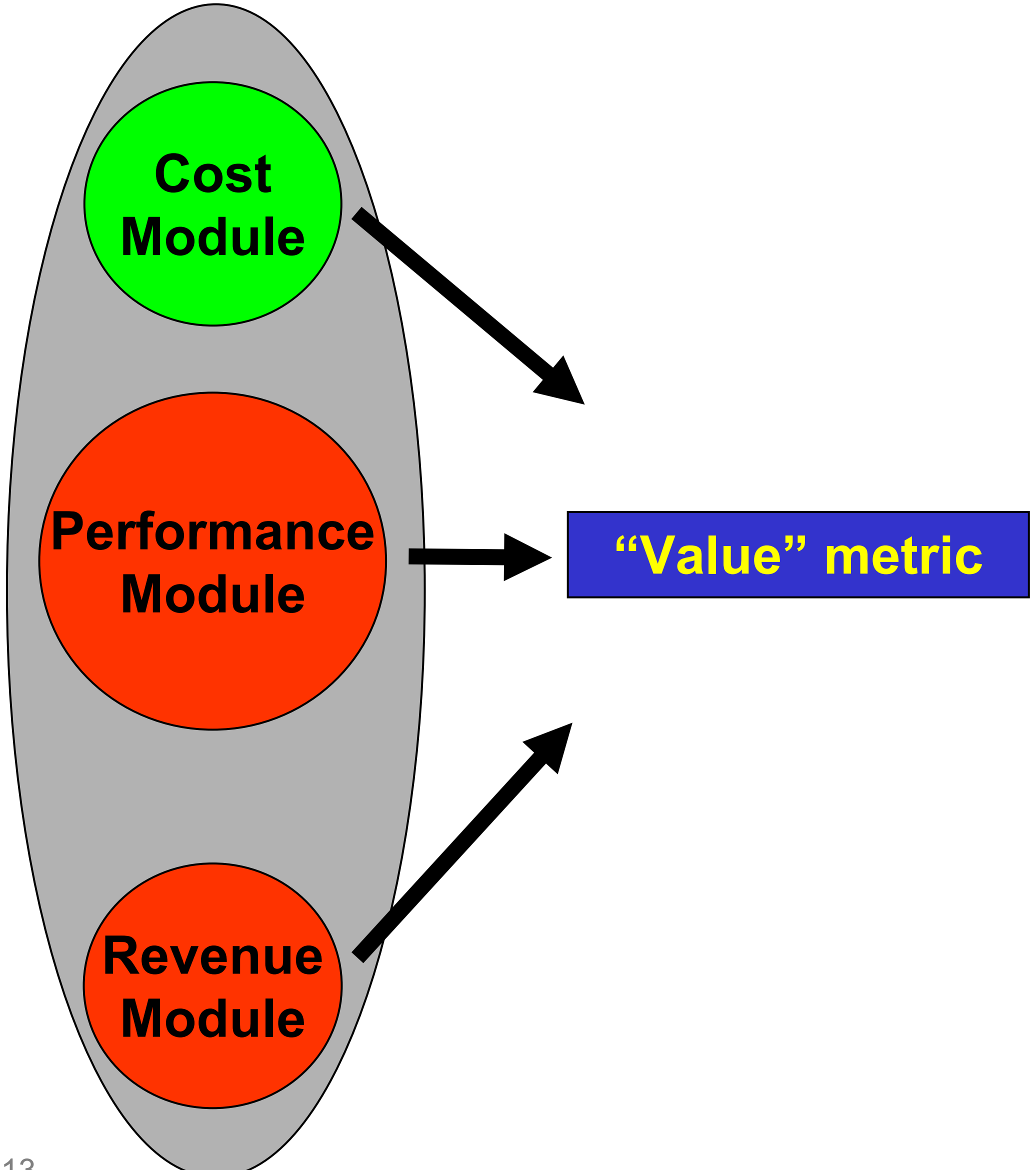
Value Optimization Framework



Challenges

- Cost and revenue are difficult to model
  - often models are based on empirical data
  - how to predict for new designs
- Uncertainty of market
- Long program length
- Time value of money
- Valuing flexibility
- Performance/financial groups even more uncoupled than engineering disciplines

Cost Model



Need to model the lifecycle cost of the system.

Life cycle :

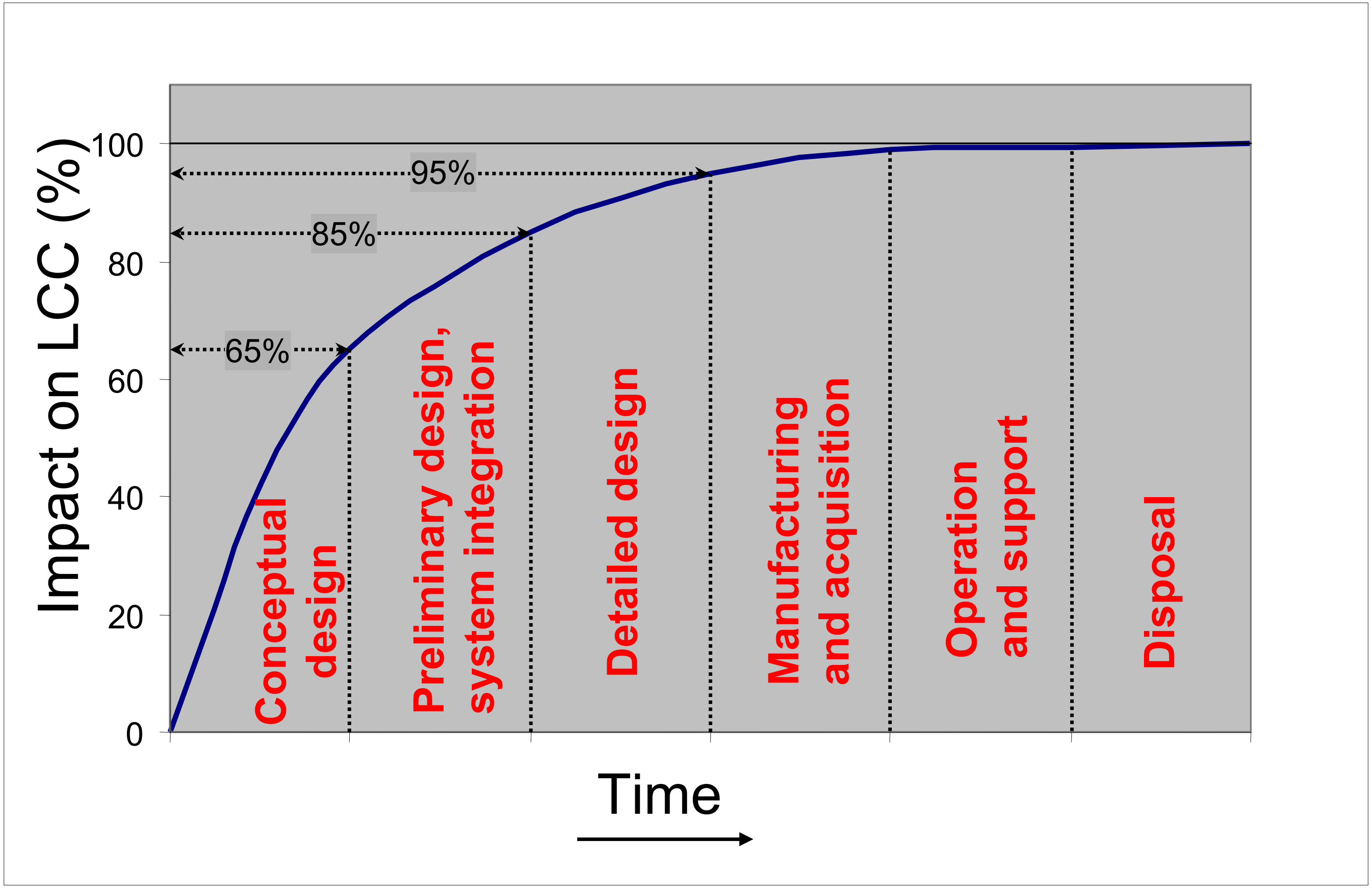
Design - Manufacture - Operation - Disposal

Lifecycle cost :

Total cost of program over life cycle

85% of Total LCC is locked in by the end of preliminary design.

Lifecycle Cost



(From Roskam, Figure 2.3)

Non-Recurring Cost

Cost incurred one time only:

Engineering

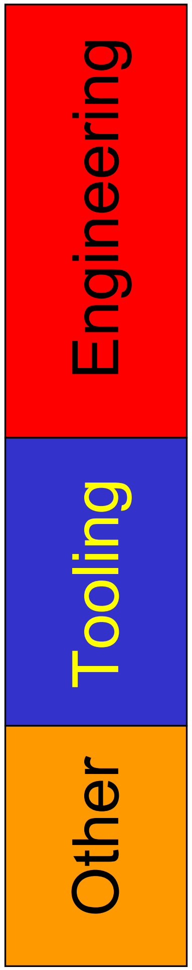
- airframe design/analysis
- configuration control
- systems engineering

Tooling

- design of tools and fixtures
- fabrication of tools and fixtures

Other

- development support
- flight testing



Cost Estimating Methods

Basic techniques to develop Cost Models:

(1) Detailed bottom-up estimating

- identify and specify lower level elements
- estimated cost of system is Σ of these
- time consuming, not appropriate early, accurate

(2) Analogous Estimating

- look at similar item/system as a baseline
- adjust to account for different size and complexity
- can be applied at different levels

(3) Parametric Estimating

- uses Cost Estimation Relationships (CER's)
- needed to find theoretical first unit (TFU) cost

Cost Breakdown Structure (CBS)

Organizational Table that collects costs, covers:

- research, development, test and evaluation (RDT&E)
- production, including learning curve effects
- launch and deployment
- operations
- end-of-life (EOL) disposal

Operations

Production

RDT&E

Space Mission Architecture

- Program Level Costs
  - Management
  - Systems Eng
  - Integration
- Space Segment
  - Payload
  - Spacecraft
  - Software
  - "Systems"
- Launch Segment
  - Launch Vhc
  - Launch Ops
  - S/C-L/V integration
- Ground Segment
  - Facilities
  - Equipment
  - Software
  - etc
- Operations and Support
  - Personnel
  - Training
  - Maintenance
  - Spares

Parametric Cost Models

Are most appropriate for trade studies:

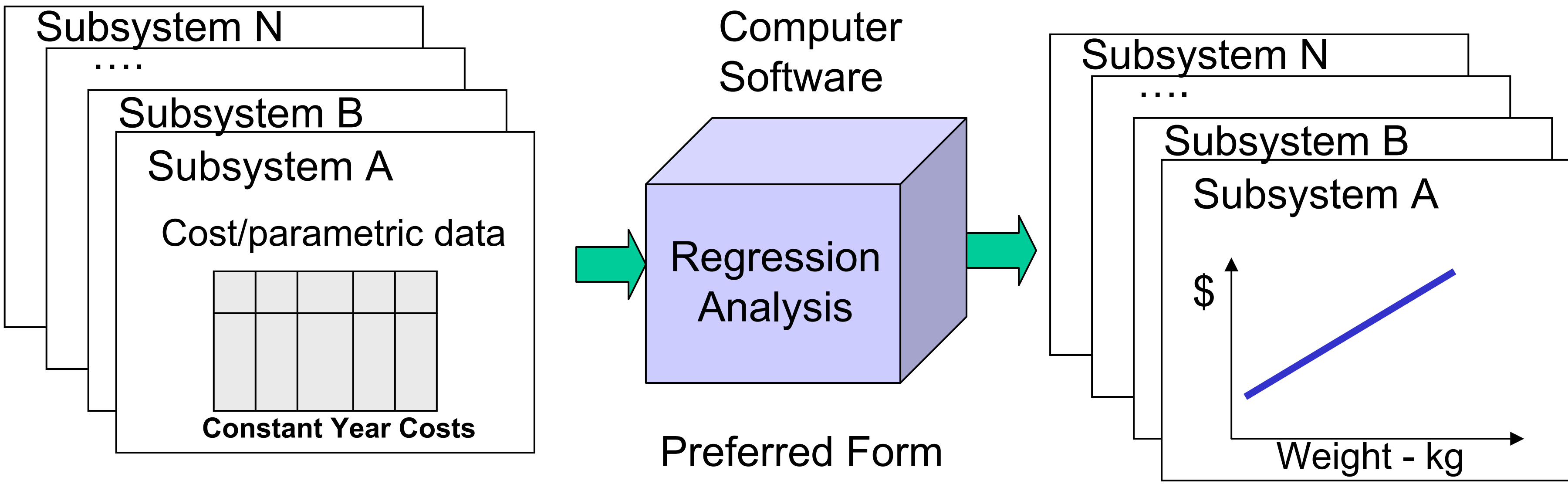
Advantages:

- less time consuming than traditional bottom-up estimates
- more effective in performing cost trades
- more consistent estimates
- traceable to specific class of aerospace systems

Major Limitations:

- applicable only to parametric range of historical data
- lacking new technology factors, adjust CER to account for new technology
- composed of different mix of “things” in element to be costed
- usually not accurate enough for a proposal bid

Process for developing CER's



Preferred Form

$$\$ = AW^b$$

Key statistics: R^2, ρ
Standard Error: RMS, σ

<u>Step 1</u>
Develop Database File

→

<u>Step 2</u>
Apply Regression Analysis

→

<u>Step 3</u>
Obtain CER's and Error Statistics

(Cost Model Assumption)

Adjustment to constant-year dollars

It is critical that cost estimated be based on a constant-year dollar bases. Reason: INFLATION

E.g. All costs are adjusted to FY92 ("Fiscal Year 1992")

$$C_Y = R \cdot C_{Y-N}$$

Past Years

Use actual inflation numbers

$$R = \underbrace{(1.040)}_{FY92}\underbrace{(1.037)}_{FY93}\underbrace{(1.034)}_{FY94} = 1.115$$

Convert Oct-1991 cost to Oct-1994 costs

Future Years

$$R = (1 + i_{RATE})^N$$

Use forecasted inflation numbers
e.g. 3.1% yearly inflation in U.S.

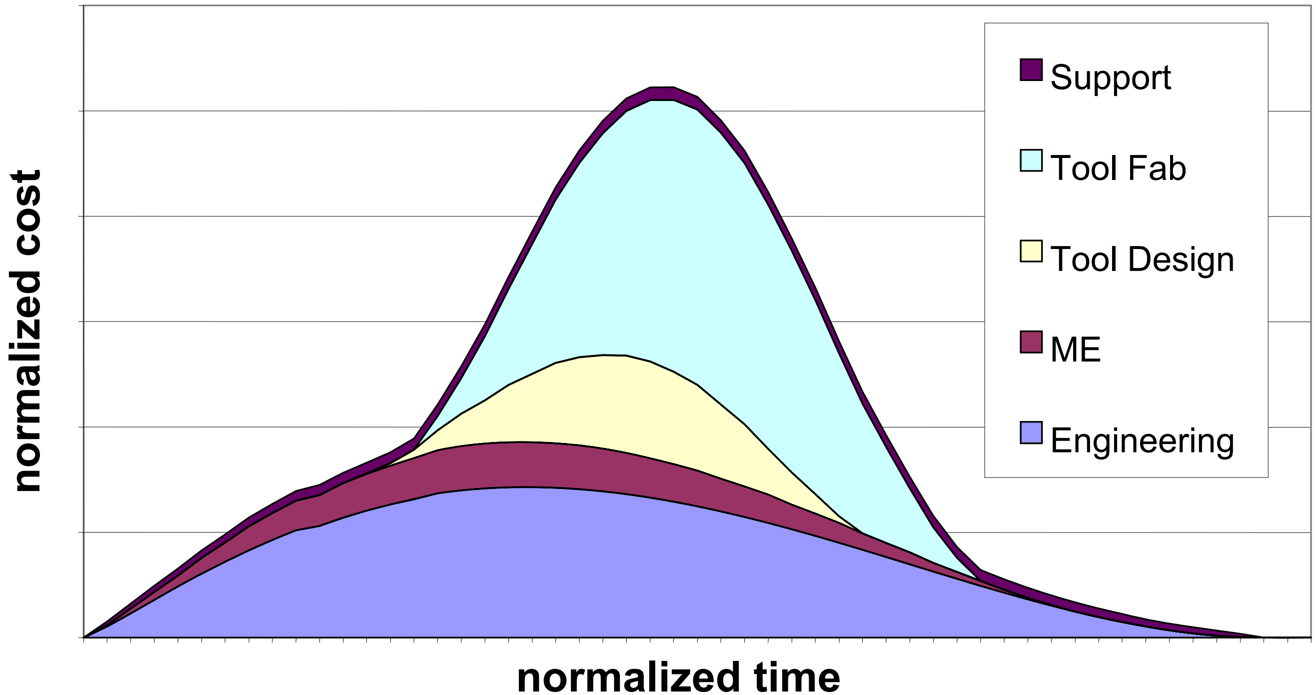
$ 1M in FY 1980 corresponds to
$ 2.948M in FY 2005

Development Cost Model

- Cashflow profiles based on beta curve:

$$c(t) = Kt^{\alpha-1}(1-t)^{\beta-1}$$

- Typical development time ~6 years
- Learning effects captured – span, cost



(from Markish)

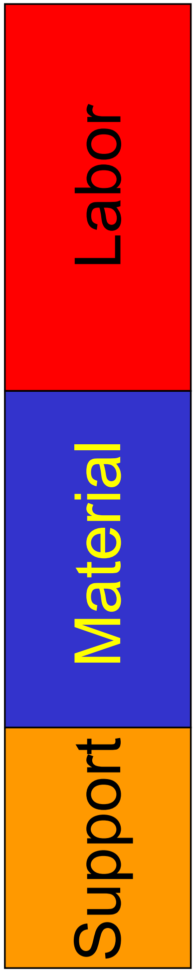
Recurring Cost

Cost incurred per unit:

Labor
- fabrication
- assembly
- integration

Material to manufacture
- raw material
- purchased outside production
- purchased equipment

Production support
- QA
- production tooling support
- engineering support



Learning Curve

As more units are made, the recurring cost per unit decreases.

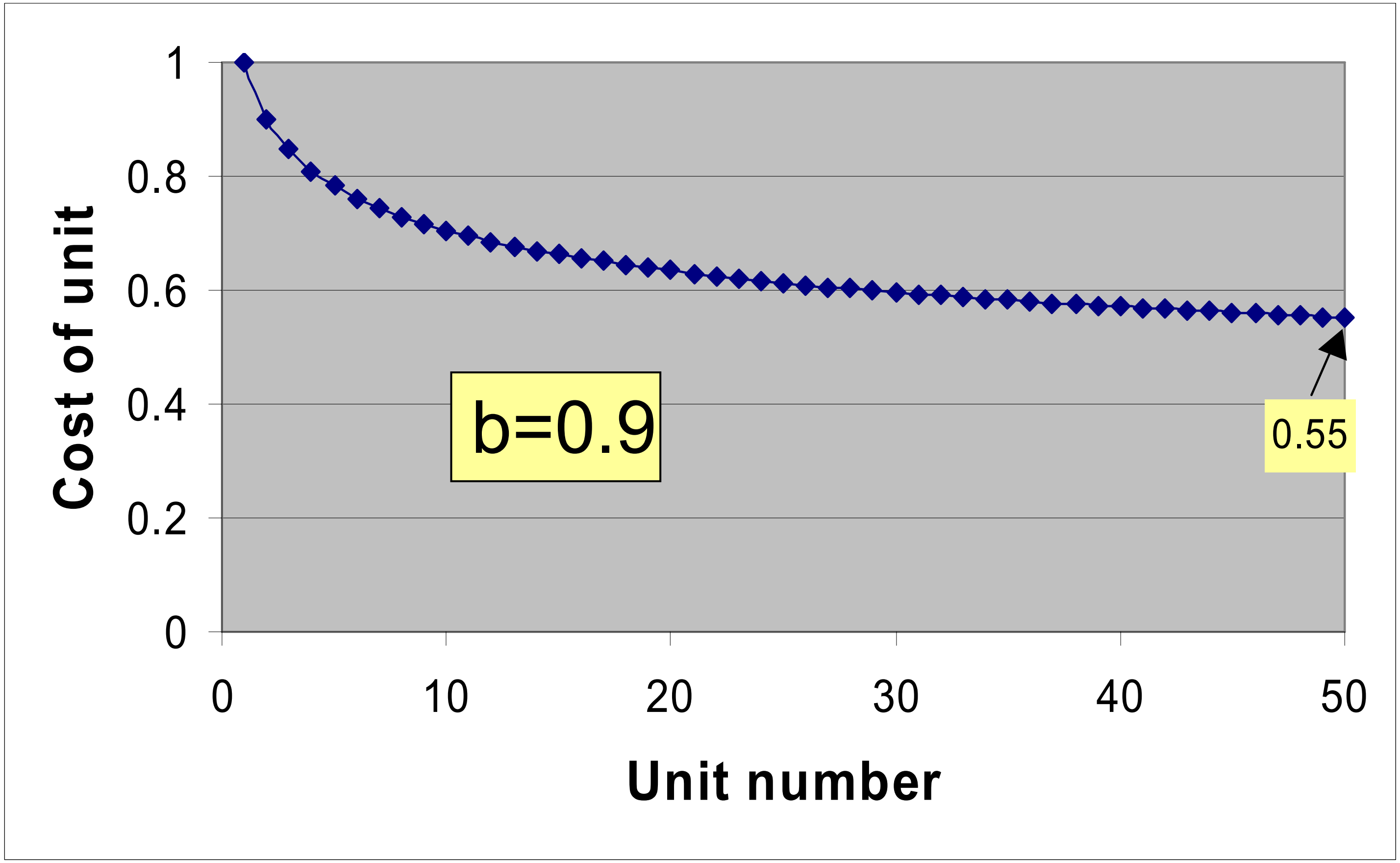
This is the learning curve effect.

e.g. Fabrication is done more quickly, less material is wasted.

$$Y_x = Y_0 x^n$$

Y_x = number of hours to produce unit x
n = log b/log 2
b = learning curve factor (~80-100%)

Learning Curve

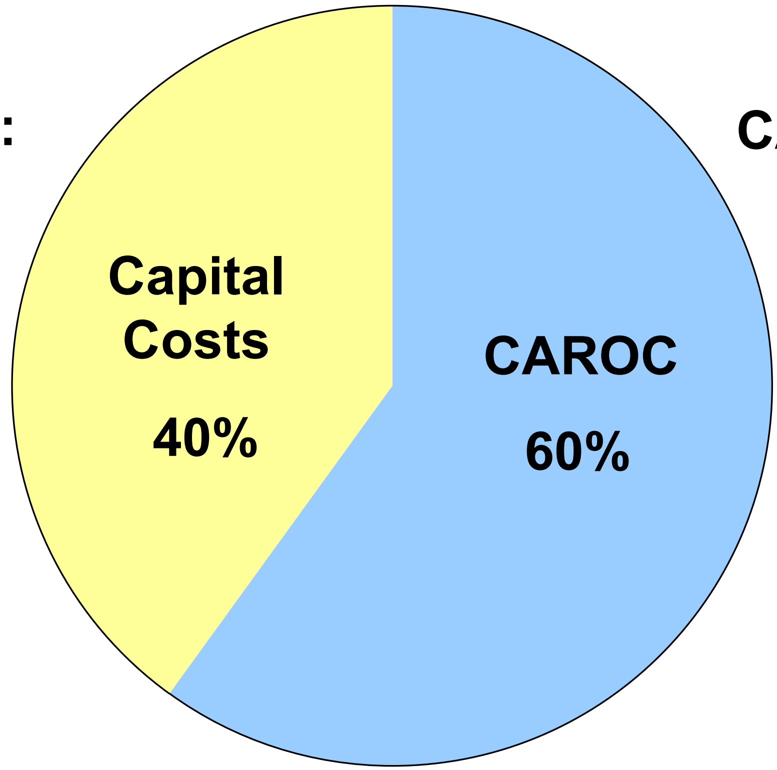


Every time production doubles, cost is reduced by a factor of 0.9

Typical LC slopes: Fab 90%, Assembly 75%, Material 98%

Airplane Related Operating Costs

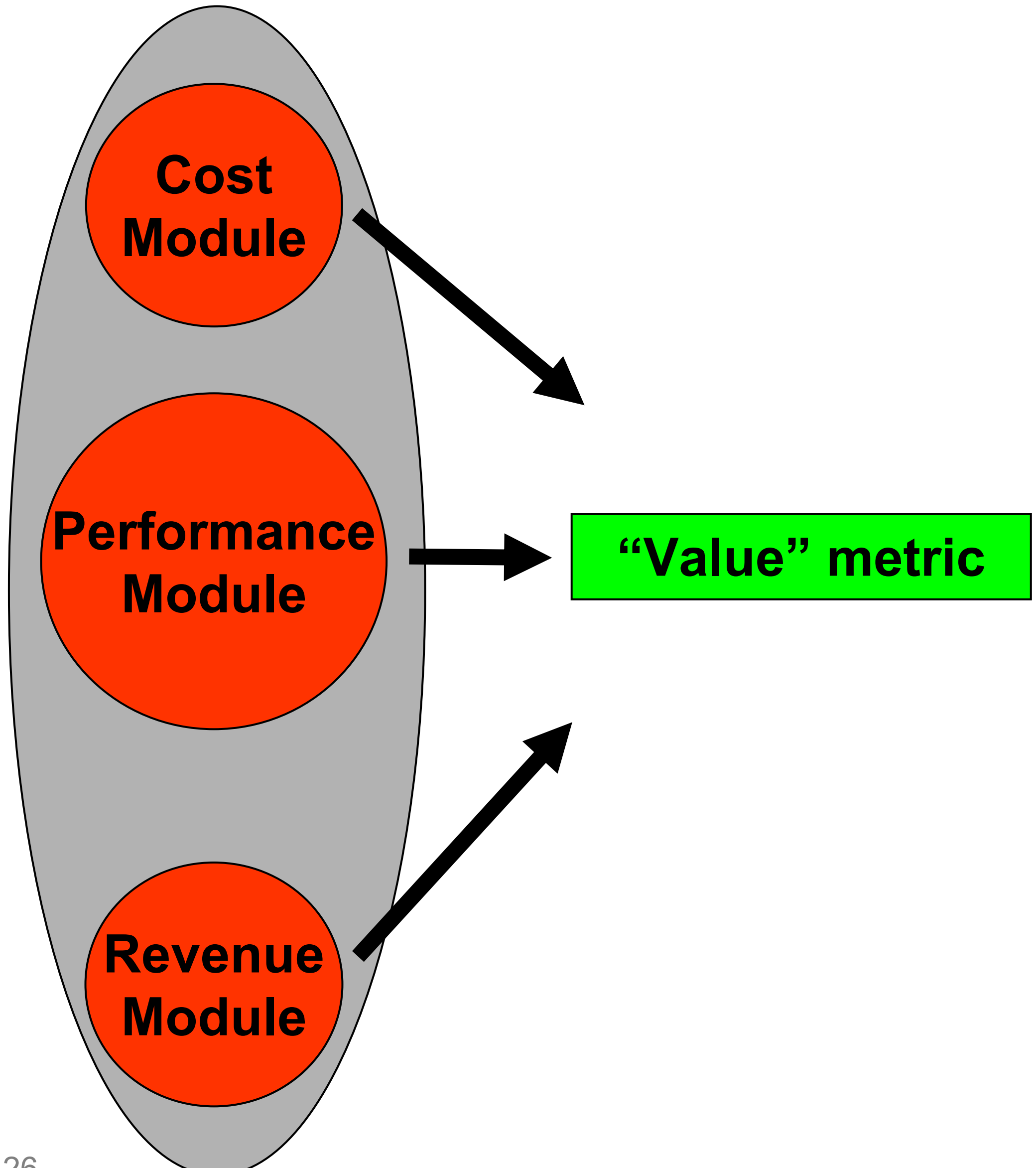
CAPITAL COSTS:
Financing
Insurance
Depreciation



CASH AIRPLANE RELATED OPERATING COSTS:
Crew
Fuel
Maintenance
Landing
Ground Handling
GPE Depreciation
GPE Maintenance
Control & Communications

CAROC is only 60% - ownership costs are significant!

Value Metric



Need to provide a quantitative metric that incorporates cost, performance and revenue information.

In optimization, need to be especially carefully about what metric we choose...

Value Metrics

Traditional Metrics	Augmented Metrics
performance weight speed	cost revenue profit quietness emissions commonality ...

The definition of value will vary depending on your system and your role as a stakeholder, but we must define a quantifiable metric.

Net Present Value (NPV)

- Measure of present value of various cash flows in different periods in the future
- Cash flow in any given period discounted by the value of a dollar today at that point in the future
  - “Time is money”
  - A dollar tomorrow is worth less today since if properly invested, a dollar today would be worth more tomorrow
- Rate at which future cash flows are discounted is determined by the “discount rate” or “hurdle rate”
  - Discount rate is equal to the amount of interest the investor could earn in a single time period (usually a year) if s/he were to invest in a “safer” investment

Discounted Cash Flow (DCF)

- Forecast the cash flows, C_0, C_1, ..., C_T of the project over its economic life
  - Treat investments as negative cash flow
- Determine the appropriate opportunity cost of capital (i.e. determine the discount rate r)
- Use opportunity cost of capital to discount the future cash flow of the project
- Sum the discounted cash flows to get the net present value (NPV)

$$NPV = C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}$$

DCF example

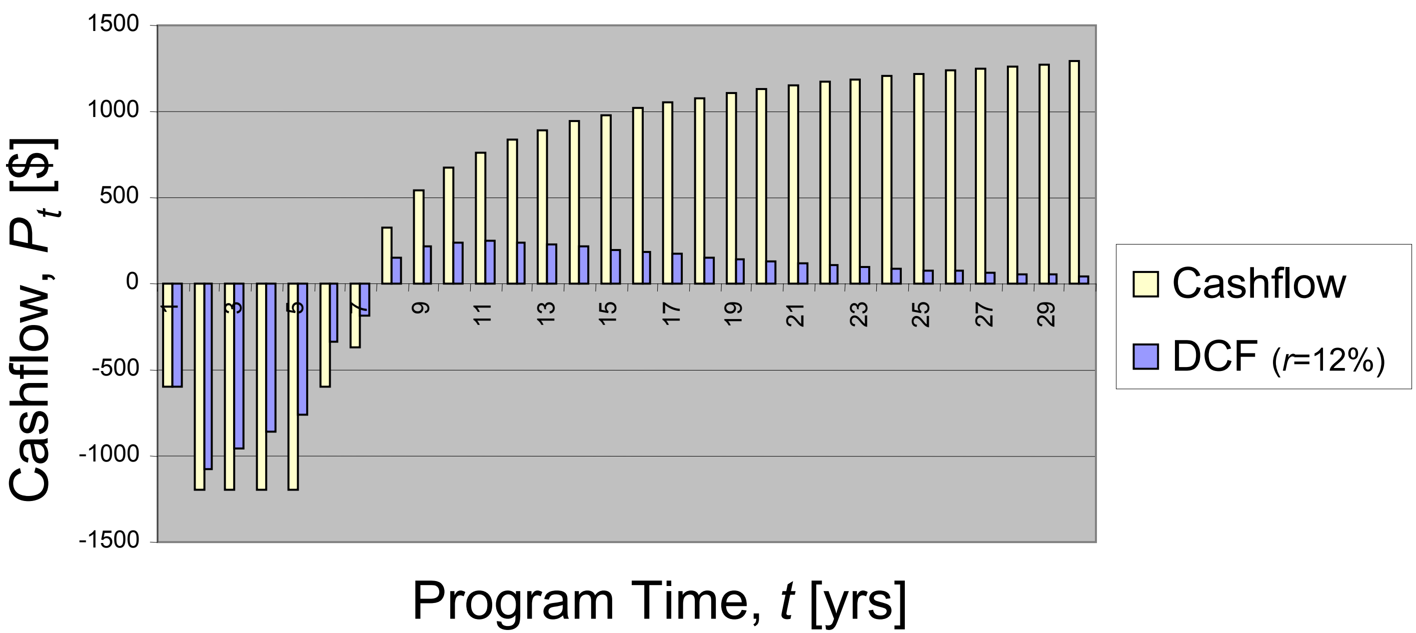
Period	Discount Factor	Cash Flow	Present Value
0	1	-150,000	-150,000
1	0.935	-100,000	-93,500
2	0.873	+300000	+261,000

Discount rate = 7%

NPV = $18,400

Net Present Value (NPV)

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t}$$



Return on Investment (ROI)

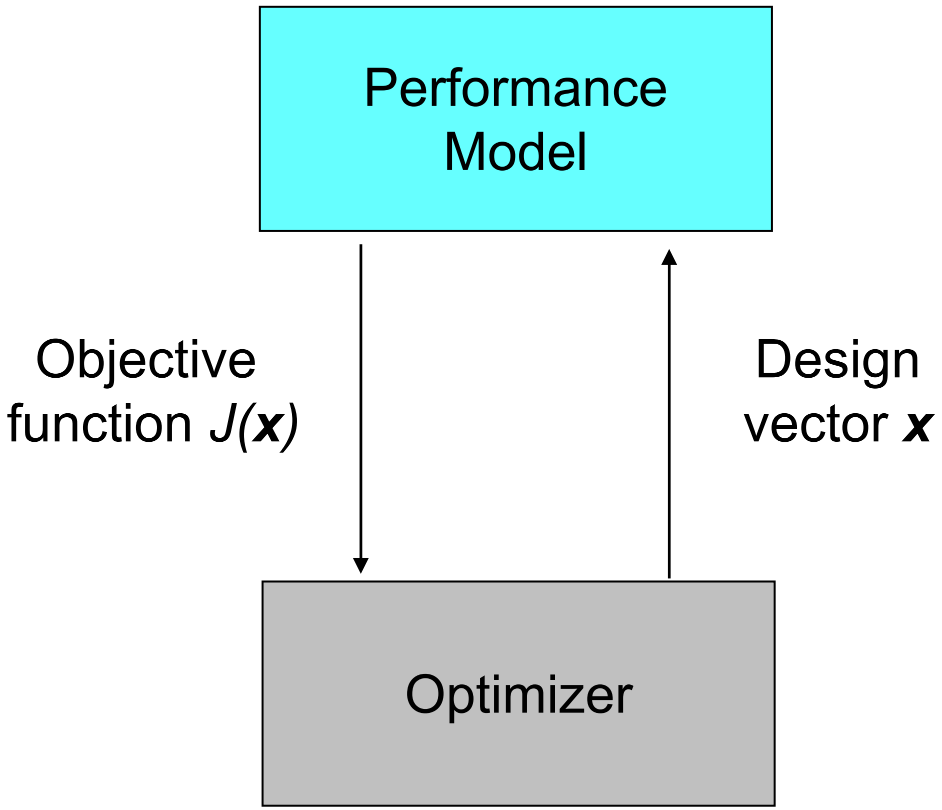
- Return of an action divided by the cost of that action

$$ROI = \frac{\text{revenue} - \text{cost}}{\text{cost}}$$

- Need to decide whether to use actual or discounted cashflows

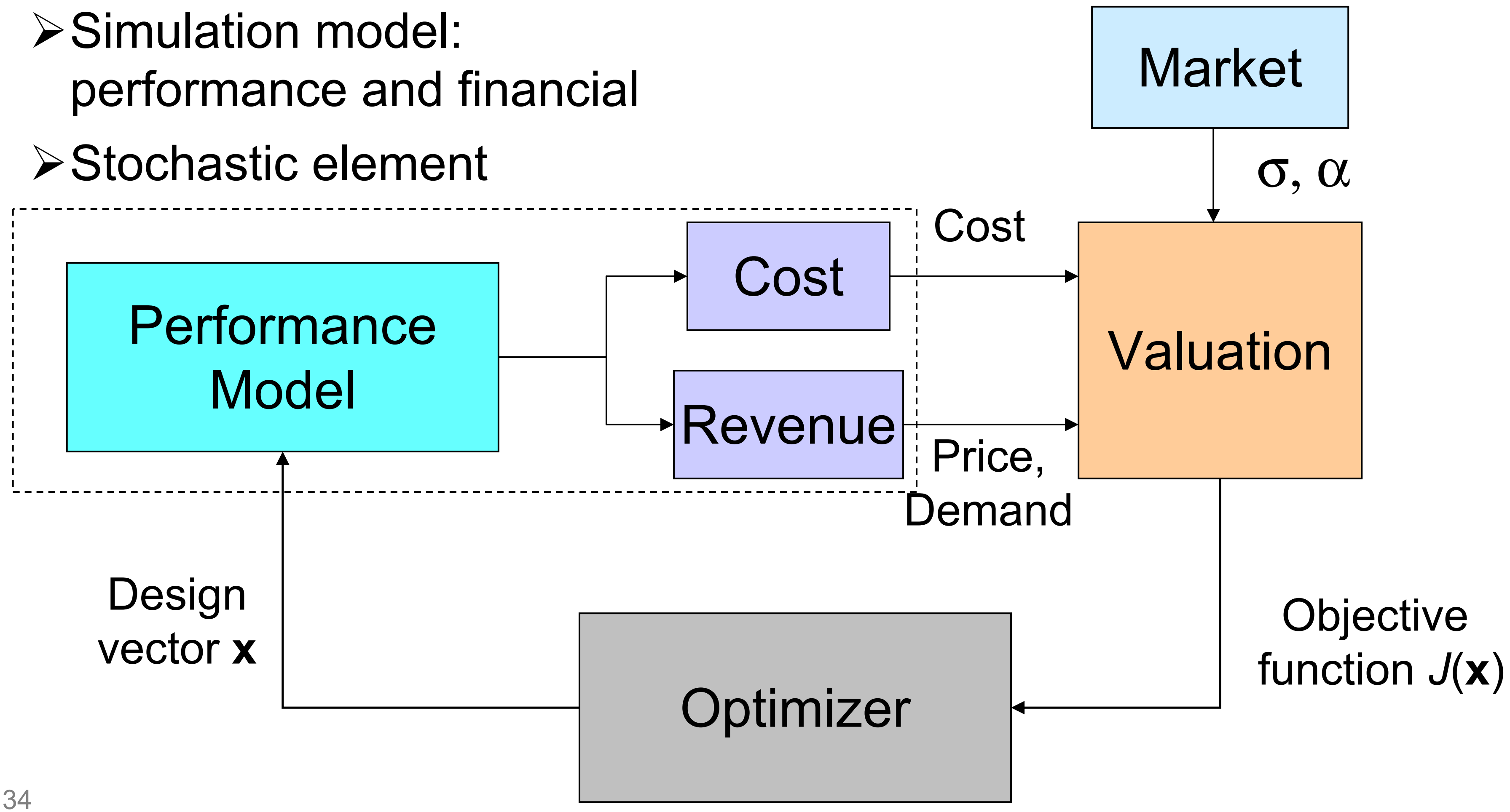
Traditional Design Optimization

- Objective function: usually minimum weight
- Design vector: attributes of design, e.g. planform geometry
- Performance model: contains several engineering disciplines



Coupled MDO Framework

- Objective function: value metric, e.g. NPV
- Simulation model: performance and financial
- Stochastic element



Summary

- Lifecycle Management
  - Operations phase is often the longest and most expensive
  - Design for maintainability, upgrades, evolution …
- Lifecycle Modeling
  - Cost = Non-recurring + Recurring, Fixed + Variable
  - Revenue, Value
  - Others … e.g. energy consumption, carbon footprint …
- Take 16.888 Multidisciplinary System Design Optimization in Spring 2010 if you want more !
- Online final exam will be posted this weekend by Dec 6, 2009 at the latest – 4 days to respond (open book)
- Friday, Dec 11 – social event (LEGO Mind Storms)

Thank you!

TA: Maj. Jeremy Agte … could not have done it without you !

Happy Holidays !